Preliminary Summary of Street Maintenance Simulations

Executive Summary

During each budget process, the City Council must weigh the funding needs for a variety of programs and services. After the 2008 recession took hold in Weatherford, it was necessary to reduce street funding levels in order to continue providing all of the amenities that the citizens of Weatherford desire. Since those initial reductions, the street maintenance budget has seen some funding returned, although it has not been made completely whole. As budget discussions were held in the summer of 2012, the City Council requested information on adequate funding levels for the City's street system. This report is an attempt to answer that question.

To achieve this goal, a simulation model was developed to test the effectiveness of various funding scenarios over a period of time. These simulations were conducted based on data from a survey conducted in 2006, as well as condition projections maintained since 2009 by the Transportation & Public Works Department. The results presented here, however, are exclusively based on the 2006 data.

Statistical tests were run on the results of each simulation and scenario. Analysis indicates that current funding levels would not have been sufficient to maintain the street system's overall condition level as it existed in 2006. The same is true for scenarios involving modest increases over current funding.

The results did find a funding scenario that achieved a level of long-term equilibrium (over a period of 80 years) that was achievable. Indeed, pre-recession funding levels were not too far below the equilibrium level.

Finally, it should be noted by the reader that, because the simulations were conducted on the original 2006 data, this report should be considered preliminary. Its value at the time of publication is primarily to enhance the conceptual understanding of how a street system's condition changes over time, and to determine a funding mechanism that can achieve long-term equilibrium. The original data are slated to be updated by the same survey company that the City hired in 2006. When these data are available, the simulations will be run again to gain better insight on appropriate funding based on current condition levels.

Background

In 2006, Infrastructure Management Services (IMS) was hired by the City of Weatherford to conduct a pavement condition survey. IMS conducted a thorough analysis of all City maintained streets, breaking down each street into segments and rating the pavement quality from 0 to 100 based on 11 individual types of distress.

Due to budget constraints, the need to prioritize street repairs is critical. Beginning in 2009, the Transportation & Public Works Department (TPW) began keeping updated projections of pavement quality using the original data while taking into account rehabilitation and preventive maintenance that had been performed since those data were collected. Since that time, TPW has used these projections to prepare five-year street maintenance schedules.

In 2013, IMS will return to update its initial pavement condition survey. This new survey will be incorporated into the simulation model described below. The simulations will be re-run, and the results will be republished for consideration with TPW's FY14 budget request and future project list.

Terminology

This section will briefly define terms that are used in the remainder of this document.

Term	Definition
Normality	Or a normal distribution, is the distribution of a dataset such that observations at or around the average occur with a higher probability than those farther away from the average. A Bell Curve is a graphical representation of a normal distribution.
Significance	Significance in statistics refers to the degree of confidence one can have in making an inference about a population by using a sample of that population. For example, while there may be an apparent difference between a mean of 60 and 62, if there is no statistical significance, it means we cannot meaningfully distinguish between the datasets. Consider also the margin of error reported in political polling.
Standard Deviation	A measure of the spread of observations in a dataset from the average value.
Pavement Condition Index	Or PCI, is the terminology used by the City of Weatherford to refer to the numerical quality associated with a street. Values range from 0 to 100.
Street System	Refers to the series of streets and roads the maintenance for which the City of Weatherford is responsible.
Street Segment	Refers to a portion of a street which is uniquely identified within the City's database. If often refers to a city block, but may in some cases be larger or smaller than that. Each segment has its own PCI.
Current Repair Cost	Or CRC, is a comparison statistic used by the City of Weatherford. It is calculated by taking all segments eligible for preventive maintenance and rehabilitation in a given year, and adding up the cost of such repairs.
Ideal Distribution	A normal distribution of PCI values for a street system such that the CRC is reduced to a manageable level.

Ideal Distribution of Street Systems for Normalized Annual Costs

In order to spread out repair costs as much as possible on an annual basis, a very specific condition distribution is required. Such a street system would be normally distributed about a mean of 65.5, with a standard deviation of about 8.5. By distributing street conditions along a relatively high average with a narrow range of dispersion, annual reconstruction needs are reduced while a greater emphasis can be placed on preventive maintenance. A distribution such as this would look similar to the graphs below.

Ideal Street Condition Distribution
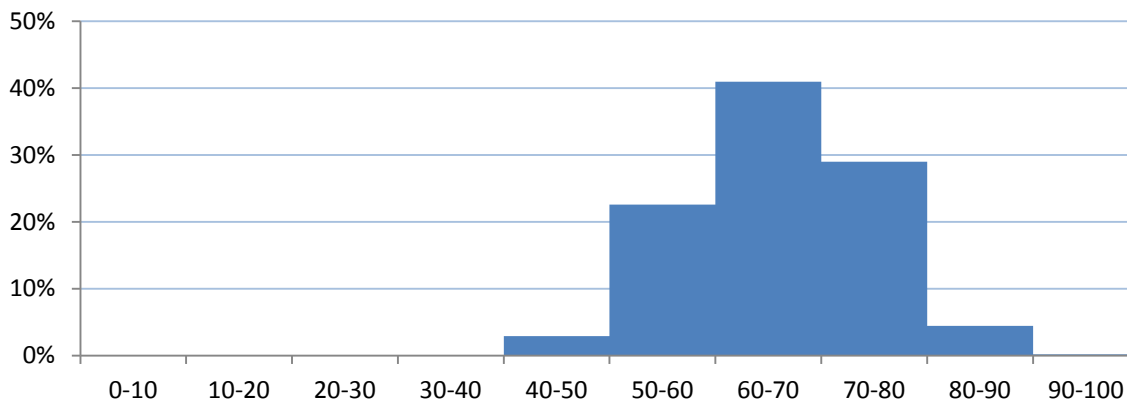
The goal of any long-term street repair program should be to achieve, as close as possible, a condition distribution that matches the one shown above. It would reduce CRC to around $2.5 million, which is a much more manageable target than the figure of more than $9 million based on 2006 condition data. By distributing the dataset in this way, the distribution among condition categories is also normally distributed (see the chart below).

Achieving this goal would require a carefully targeted maintenance program extending for decades into the future. The simulations described below attempt to estimate funding needs over a 20 year period to most closely align with the desired distribution. While the techniques used to estimate these needs can be applied to a variety of existing street systems, the answers are unique to Weatherford.

Ideal Street Condition Category Distribution
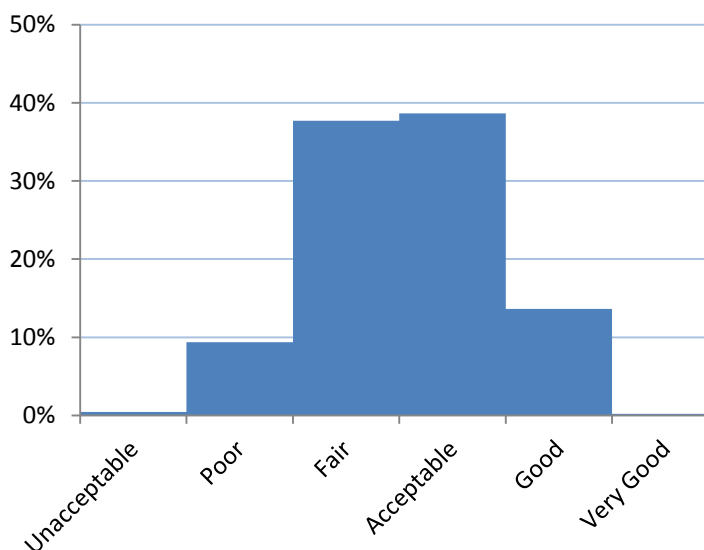
Weatherford's Initial Data

In order to determine the proper funding allocations needed to achieve an ideal distribution, it is helpful to understand the starting point. In 2006, Weatherford contracted with IMS to prepare an extensive survey of street conditions within the city. The distribution resulting from that study is shown below[1]:

2006 Condition Distribution
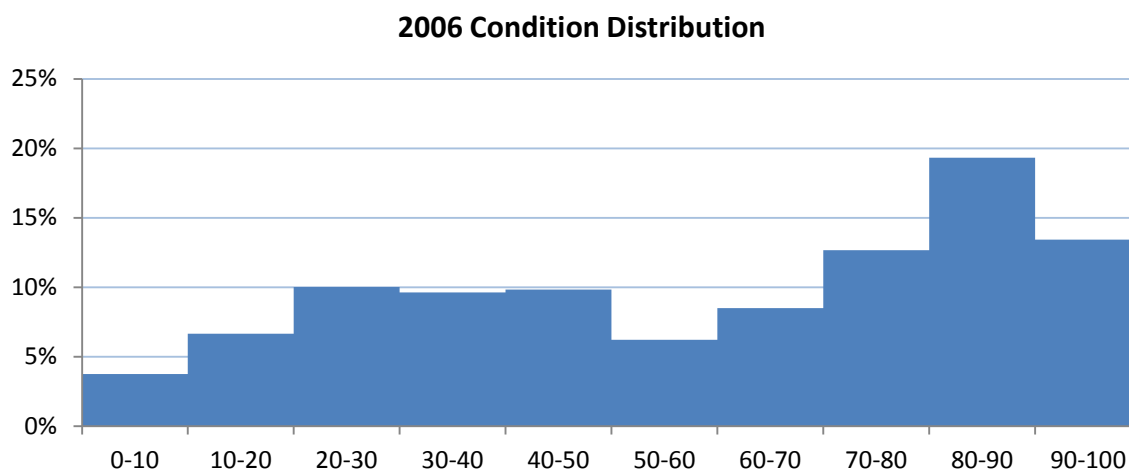
Whereas less than 1% of segments should be rated below 40, around 30% of Weatherford's segments fell into that category. Fully two-thirds should fall between 50 and 70, while only 15% met that criterion in 2006. Finally, around 5% should be between 80 and 100, while nearly 33% fell into that group in 2006.

While an eyeball test may suffice in this case, a *difference of means* test[i] (or t-test) does indeed show the difference between these samples to be statistically significant.

Summary statistics on the initial data are presented in the table below:

Statistic	Value
Mean	59.04
Median	64.05
Standard Deviation	27.73
Current Repair Cost	$9.7 million

While the average condition is not too far off from the ideal, the median is much higher, indicating a negative skew to the data[2], and the standard deviation is more than 3 times the desired level, indicating a greater spread among the data. As a result, CRC is a staggering $9.7 million.

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[i] The difference of means test is used to estimate whether two sample datasets come from the same population. The result of this test is a *t-value*, which is compared to a table of values in order to determine whether the difference between the samples is statistically significant given a desired degree of confidence (typically 95% or 99%).

Mechanics of the Simulation Model

A simulation model was constructed to test a variety of funding options over a 20 year period. Each scenario was run multiple times to ensure that results were consistent from one simulation to the next. Indeed, t-tests indicate that over 20 years, a given input will consistently yield statistically similar output. This allows for a degree of confidence that the results are not affected by random variations in the mechanics of the software (i.e., programming bugs or glitches).

Deterioration

The simulation engine utilizes industry standard deterioration schedules provided by IMS in their 2006 survey. A street segment's annual deterioration is a function of the following data:

- its composition (asphalt or cement);
- its classification (rural, arterial, etc.); and
- its previous condition rating.

As shown in the chart below, each segment will have a different annual deterioration factor based on these variables. Specifically, segments tend to deteriorate more slowly when the quality is toward the upper and lower bounds of the condition spectrum, and more rapidly when in the middle. The rate of deterioration is further adjusted based on the composition of the street and its expected traffic load.

Pavement Deterioration Schedules
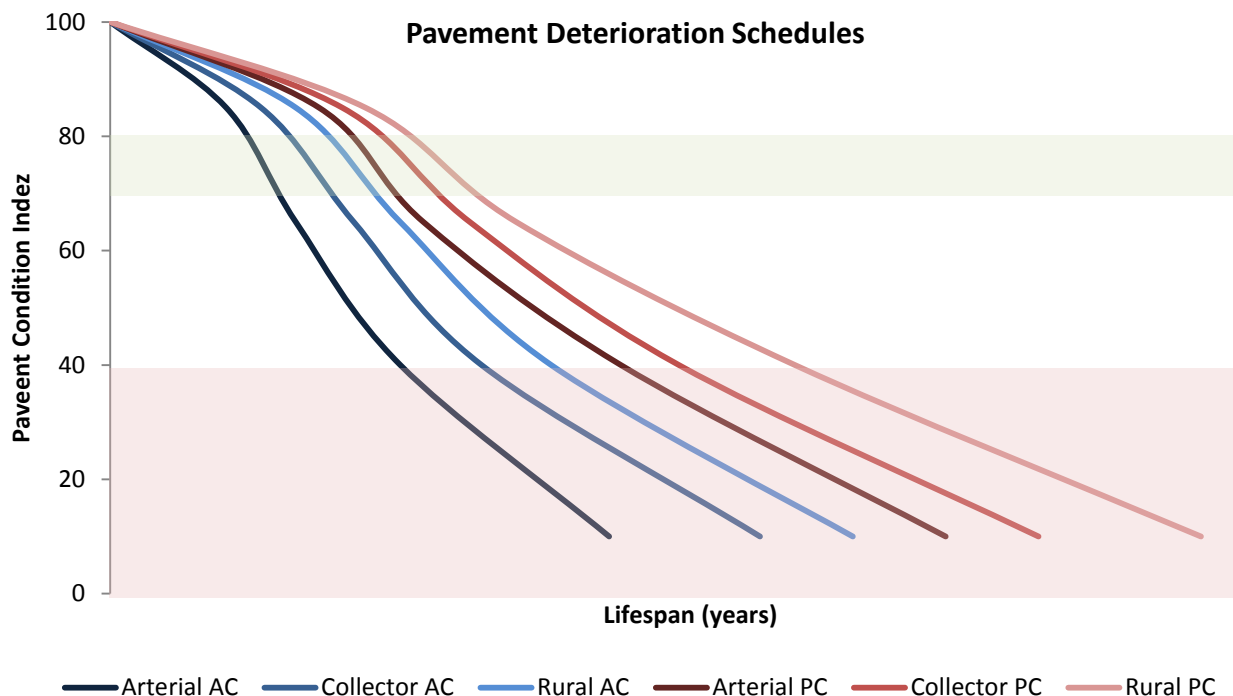
Simulating Repair Projects

Two types of repair projects are simulated: preventive maintenance and rehabilitation (or reconstruction). The City primarily uses micro-surface overlays for preventive maintenance, and in-place reclamation for rehabilitation work.

Micro-surface overlays[3] work by placing a thin (1/4 inch) layer of a emulsified asphalt mixed with crushed aggregate filler on top of the existing surface. This process creates a seal on top of the existing road and minimizes oxidation and water seepage while reducing surface friction. It can generally arrest the deterioration of a segment for 4 to 8 years. In the simulation model, when a segment has had preventive maintenance performed, its deterioration is arrested for a random amount of time between 4 and 8 years. While deterioration is still projected, it is at a much slower rate (only .5 percentage points per year compared to as many as 3.33 percentage points per year for an asphalt arterial segment).

Rehabilitation projects involve full reconstruction of a street segment. The City of Weatherford uses the technique of in-place reclamation, which recycles existing asphalt and base material to create a new subgrade, followed by an overlay of asphalt between 4 and 8 inches, depending on engineering needs. Once rehabilitated, a segment's condition is improved as if it were newly constructed. To simulate this process, a segment chosen for rehabilitation is assigned a random condition value between 95 and 99.

A summary of the impact of repair projects on a segment can be found in the table below:

Description	Preventive	Rehab
Eligible Condition Values	70-80	0-50
Cost/square yard	$3	$8
Impact on PCI	Deterioration arrested for 4-8 years	Randomly assigned between 95-99

Simulation Inputs

The simulation model takes a scenario and runs projections based on the assumptions provided. The inputs that may be adjusted are outlined below.

- Eligibility ranges for preventive maintenance and rehabilitation projects
    - Segments eligible for preventive maintenance are between 70-80 PCI
    - Segments eligible for rehabilitation are between 0-50 PCI
- Years to simulate
    - Most simulations shown in this report are 20 years in length
- Repair cost
    - Preventive maintenance is averaged at $3 per square yard
    - Rehabilitation is averaged at $8 per square yard
- Budget levels
    - Budget levels are provided for both types of repair projects, and can be set individually for each year of the simulation.

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By adjusting the various inputs, the simulation model allows for hypotheses testing in order to determine the efficacy of funding scenarios.

Cost Assumptions

In order to reduce complexity of the simulation model, all costs are assumed in constant dollars. In other words, it is taken as a given that the purchasing power of the street maintenance budget will be held constant relative to any inflationary pressures that will occur during the forecast.

Presentation of Results

Summary results of each scenario are included in this report[4]. Categorical condition distributions will be shown for the results after 20 years. Due to the fact that any given set of scenarios will produce statistically similar outcomes, results for each scenario were randomly selected for comparison purposes.

Categorical condition distributions include the percentage of the street system found in each condition category as follows:

Category	Value Range
Unacceptable	0-45
Poor	45-55
Acceptable	55-65
Fair	65-75
Good	75-90
Very Good	90-100

Difference of means tests were run to determine statistical differences for Year 20 among each scenario. The ultimate goal of these trials would be to find some combination of funding levels that result in no statistical difference after the final year of simulation from the ideal distribution discussed above.

Summary of Initial Scenario Results

A variety of scenarios were initially devised to test the impact on the City's condition distribution. After running these initial scenarios, several more were added to provide additional insight.

The following scenarios were used to established baselines for comparison:

Scenario	Preventive Budget	Rehab Budget
No Funding (baseline)	$0	$0
Current Funding Levels (Scenario 1)	$50,000	$400,000

The following scenarios were used to compare the efficacy of additional preventive maintenance funding versus rehabilitation. Scenarios 2 and 3 added $50,000 to the rehabilitation and preventive maintenance budgets, respectively. Scenarios 4 and 5 added $100,000 in the same manner:

Scenario	Preventive Budget	Rehab Budget
Scenario 2	$50,000	$450,000
Scenario 3	$100,000	$400,000
Scenario 4	$50,000	$500,000
Scenario 5	$150,000	$400,000

In each of the scenarios outlined above, the results showed statistically significant deterioration when compared to the initial dataset. In other words, none of these scenarios were able to hold the condition of the City's street system constant, let alone set it on a path to an ideal distribution.

The categorical distributions for Year 20 of each scenario are shown in the series of charts below:
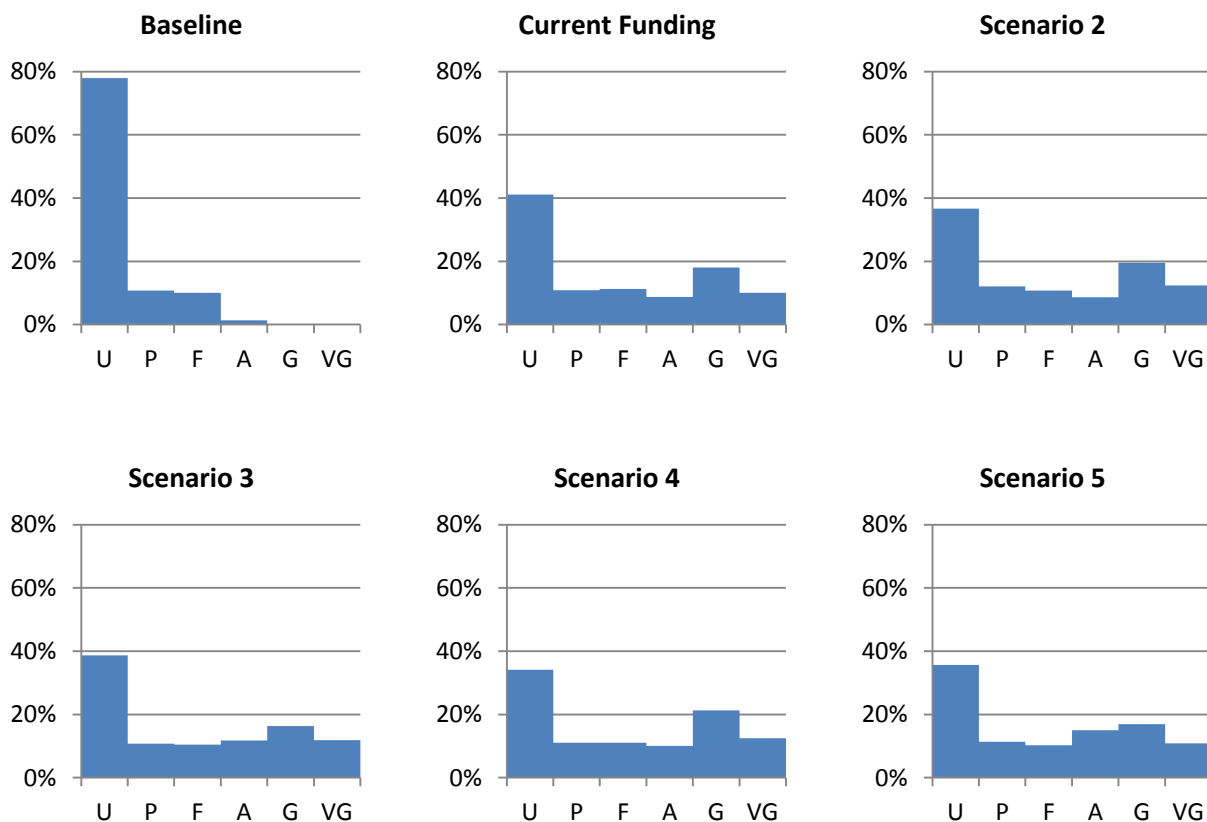
The results are shown on the same scale as the baseline scenario (no funding) for the sake of comparison. It is important to note that although none of these funding scenarios were sufficient to maintain the City's starting average condition, scenarios 2, 4, and 5 represented a statistical improvement relative to current budget levels. Scenario 3, however, was not statistically different from current budget levels.

The results are summarized in the table below[ii]:

Scenario	Vs. Initial	Vs. Current Funding	Average PCI	CRC
Baseline	Worse	Worse	27.73	$18.1 m
Current Funding Levels	Worse	N/A	52.07	$10.9 m
Scenario 2	Worse	Better	55.09	$10.1 m
Scenario 3	Worse	No Difference	52.97	$10.3 m
Scenario 4	Worse	Better	56.46	$9.3 m
Scenario 5	Worse	Better	54.49	$9.5 m

The results from the initial scenarios indicate that even a relatively modest increase in rehabilitation funding would result in a statistical improvement over current funding levels. Preventive maintenance can also help (at sufficient levels) although a $100,000 increase in preventive maintenance would not be statistically preferable to a $50,000 increase in rehabilitation funds.

Results of Scenarios, Round 2

Building off of these results, we sought to devise scenarios wherein the overall street quality could be improved over 20 years, or at least kept from seeing significant deterioration. The following chart shows a series of scenarios that were run with the goal of ending the 20 year simulation with an overall condition at least as good as the initial data.

Scenario	Preventive Budget	Rehab Budget
Scenario 6	$50,000	$400,000 initial, increased $25,000 every two years
Scenario 7	$50,000 initial, increased $12,500 every five years	$400,000 initial, increased $37,500 every five years
Scenario 8	$150,000	$500,000 initial, increased $25,000 each year beginning in Year 11

Scenarios 6 and 8 managed to end the 20 year simulation with system-wide condition values that were statistically similar to the initial data. Due to the five year delay in adding funding, Scenario 7 failed to maintain the initial average condition levels.

[ii] Where "Worse" or "Better" indicates a statistically significant change in the data, and "No Difference" indicates no statistically significant difference in the data.

The categorical distributions for Year 20 of each scenario are shown in the series of charts below:
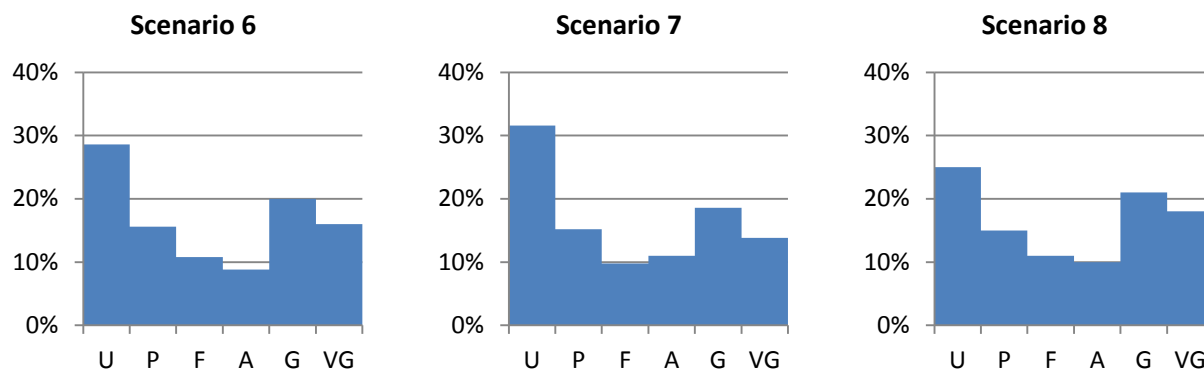
The results are summarized in the table below:

Scenario	Vs. Initial	Vs. Current Funding	Average PCI	CRC
Scenario 6	No Difference	Better	57.6	$9.0 m
Scenario 7	Worse	Better	55.5	$9.8 m
Scenario 8	No Difference	Better	60.3	$8.1 m

Scenarios 6 and 8 represented an improvement from current funding, and exceeded the results from every initial scenario in that they ended with no statistical difference from the starting values. They would represent two possible funding scenarios which would allow the City to keep its street system at a consistent level, partially bending the cost curve in the right direction.

Looking more deeply into the results, however, revealed that in the first ten years of these scenarios, condition data improved markedly before falling off toward the end of the forecast. Using this information, additional scenarios were devised in an attempt to actually improve the street system during the 20 year window.

Scenario for Stabilizing the Street System

After running and analyzing the scenarios above, an attempt was made to find a budget level and allocation sequence that stabilized the street system. Instead of using the shorter 20 year time period, the simulation term was extended to 80 years.

To establish a top level spending assumption, annual budgets for rehabilitation and preventive maintenance were set at $1.5 million and $200,000, respectively. The purpose of this simulation was to see if, at a significantly higher budget level, the street system could be stabilized. While the results are not presented here, they led to an interesting finding. For the first 10-12 years, the entire rehabilitation budget was used, but for the next 10-12 years, there were only enough projects to use approximately half of it. This pattern continued throughout the simulation window, resulting in significant inefficiencies due to recurring periods of time where large portions of the available budget remained unspent, while overall street conditions did not appreciably improve.

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When analyzing the data from this simulation, it became clear that the ebbs and flows of potential projects mirrored the trigonometric functions sine and cosine. In other words, with a stable funding level, the appropriate allocation between rehabilitation and preventive maintenance should oscillate based on the types of projects available in a given year.

A final scenario was simulated based on this information by leaving the total budget at a constant level and adjusting the percentage allocated toward either rehabilitation projects or preventive maintenance. The assumptions are shown below:

Scenario	Preventive Budget	Rehab Budget	Total Budget
Scenario 9	$100,000 to $350,000	$775,000 to $1,025,000	Constant at $1,125,000

By adjusting the available budgets along a sine/cosine curve, while keeping the total funding level constant, this scenario resulted in three positive outcomes.

Nearly all available funds were able to be spent

The total budget for this simulation was $90 million over an 80 year period. During that time, only $76,605 (or less than 0.01%) was left unspent. Budget levels versus simulated expenditures can be seen in the chart below:

Simulated Budget vs Actual
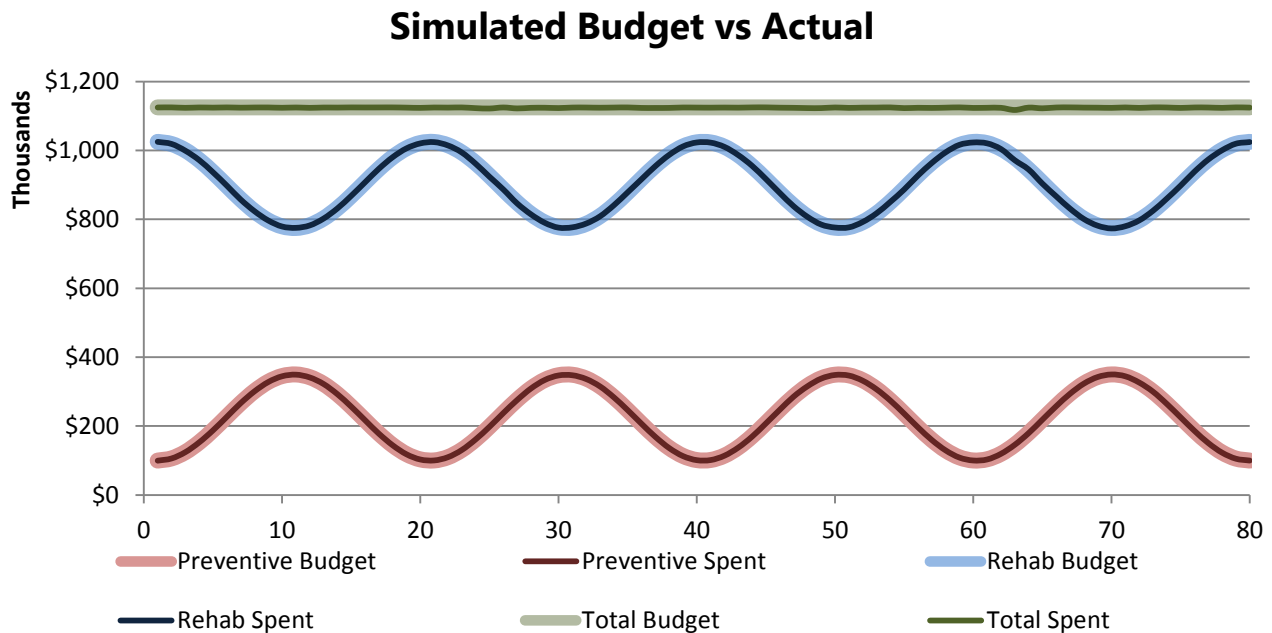
Average PCI stayed between 67 and 74 beginning in Year 10

After Year 10, the average PCI score stabilized between 67 and 74, and remained within that range for the duration of the simulation.
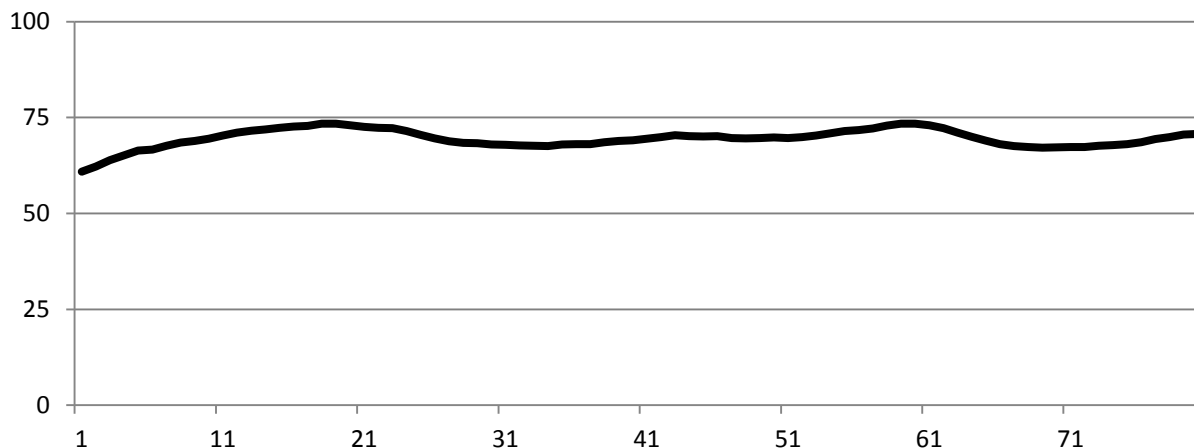
Current Repair Costs stabilized at manageable levels throughout the simulation

Although current repair costs did fluctuate between $2 and $6 million, this measure tended to rise as the rehabilitation funding was temporarily shifted to preventive maintenance and fall as funding shifted back to rehabilitation projects. Overall, this measurement was stable over the simulation period.
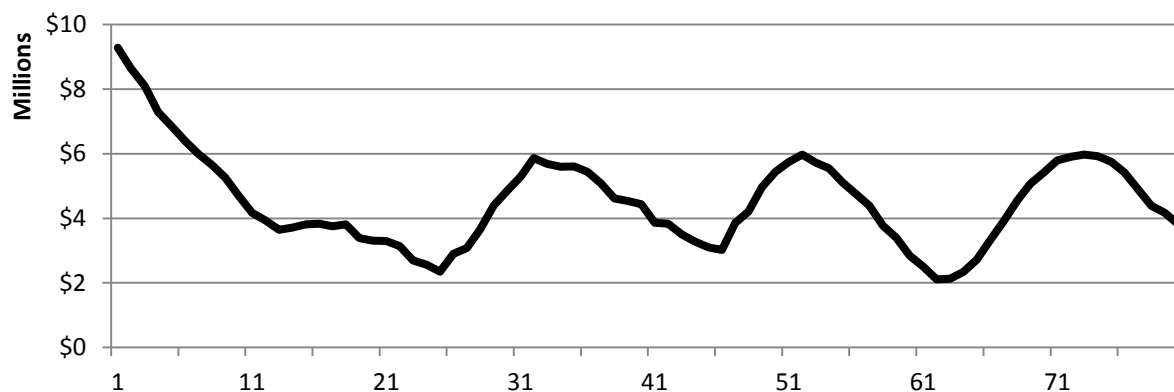
Summary and Future Efforts

There are a number of important findings from this study. First, in 2006, the average condition of Weatherford's street system was good. However, considering only the average pavement condition can mask potential areas for improvement. Notably, although the average was around 59, a great number of streets were in the lower categories. This resulted in a large up-front need for street maintenance resources. At that time, street maintenance funding levels were much closer to the final scenario presented in this report than they are today. Shortly after the initial survey was conducted, general revenues declined precipitously as the national housing market collapsed and the economy fell into recession. Street funding (as well as staffing) fell to accommodate this decline.

Second, the model shows that today's funding levels would not be sufficient to maintain the street system's overall condition level compared to the initial 2006 survey. Indeed, even the addition of up to $100,000 per year is unlikely to prevent statistically significant deterioration from occurring compared to the 2006 data.

Third, more aggressive funding scenarios are likely necessary to bend the cost curve and enable the City to maintain overall condition levels relative to the 2006 survey. However, the efficacy of any given scenario is dependent upon the size and swiftness of any funding increases.

Finally, a street system is an ever-changing creature, and funding allocations between preventive maintenance and rehabilitation must be constantly adjusted in order to maintain a level of homeostasis.

While this report indicates that additional funding would be needed to achieve such equilibrium, there is a bright spot. When IMS reported the results of the 2006 survey, it was estimated that the City would need up to $1.75 million in annual street funding. This study has shown that by strategically allocating maintenance funding, that figure can be reduced by more than one-third. This is possible partially due to a constant reallocation of available funds between preventive maintenance and rehabilitation, but owes much more to the new techniques used by the Transportation & Public Works Department which have dramatically reduced rehabilitation costs since the initial survey.

It is important to note again that the results presented here are based on the original 2006 street survey, and therefore are most valuable from the standpoint of conceptualizing the issue. The simulations that were run were attempting to determine funding levels based on the City's street system as it existed more than half a decade ago.

During the spring of 2013, IMS will be returning to provide an updated survey. Condition values will be recalculated, taking into account all of the maintenance work done since 2006, and some streets will likely be reclassified which will affect their rate of deterioration. The results of this updated survey will provide a new and more accurate starting point from which to run these simulations. When the data are available, the simulations will be conducted again and the results published in a "Final" summary report for consideration during future budget discussions.

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Endnotes and References

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[1] For the full dataset, visit the City's open data web site at https://data.weatherfordtx.gov/
[2] It is important to note that having a median which is greater than the mean is not always indicative of a negatively skewed distribution, although in this instance that rule of thumb holds up.
[3] For more information on micro-surfacing, download this PDF presentation from UC Berkeley:
http://www.techtransfer.berkeley.edu/pavementpres08downloads/PP08Olsen.pdf
[4] For full results, visit the City's open data web site at https://data.weatherfordtx.gov/